Optimizing Aquaculture: Harnessing the Growth and Immunological Benefits of Olive Plant Compounds for Blue Food Production

Rukayat Matti-Sanni - Saeio Global Limited 0000-0003-4447-5342
Isa Elegbede - Lagos State University 0000-0002-8794-8616
Segun Ajibola - Afridat UG 0000-0002-9790-6081
Muritala Ibrahim - Afridat UG 0000-0002-8623-6625
Rahmot Balogun-Adeleye - University of Lagos 0000-0003-4606-2285
Toyin Adebayo - Lautech 0000-0002-9736-928X
Vanessa Martos Núñez - Universidad de Granada 0000-0001-6442-7968
Doddy Irawan – Universitas Muhammadiyah Pontianak 0000-0003-3751-223X

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Correspondencia a través de **ORCID**: Matti-Sanni Rukayat **0000-0003-4447-5342**

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Abstract: Blue foods, sourced from aquatic ecosystems, are a diverse group of nutrient-rich foods that can play a pivotal role in improving human health and enhancing global food systems. These resources are critical to ensuring food security and addressing hunger, aligning with the United Nations Sustainable Development Goals (SDGs) 2 (Zero Hunger) and 14 (Life Below Water). This study employs secondary research approach, utilizing both qualitative and quantitative data from existing literature, explore the nutritional and developmental potential of blue foods in sustainable aquaculture. Blue foods efficiently convert energy derived from nutritionally balanced diets, high in fats, proteins, and carbohydrates, into growth and reproductive outcomes. These macronutrients support the enzymatic breakdown of lipids, proteins, and carbohydrates, facilitating efficient digestion and overall organismal development. The study focuses on the incorporation of bioactive compounds from olive plant extracts, a novel intervention to enhance blue food production and improve immunological responses in aquatic species. The findings suggest that olive plant-derived substances have positive effects on fish growth and health, indicating their potential, an innovative and sustainable resource in aquaculture. The integration of olive plant by-products into blue food systems presents a promising avenue for advancing the blue economy while promoting sustainable food production practices.

Keyword: Blue food

1. Introduction

Aquaculture is one of the fastest-growing industries in the global food sector, with fish products serving as a crucial source of blue aquatic food. This industry plays a vital role in meeting the dietary protein needs of humans (Dawood et al., 2020; Elegbede et al., 2022). Over the past 20 years, aquaculture has grown at an average annual rate of approximately 5.3%, with an output of 114.5 million tons in 2018 (FAO, 2020). This growth rate surpasses the 2.1% annual growth in other livestock and animal production sectors (FAO, 2020). Currently, 424 aquatic species are farmed globally, providing millions with sustenance, food security, livelihoods, and a means of poverty reduction (Galappaththi et al., 2020). For many, fish is an affordable, healthy source of protein and fats in their daily diets (Tacon et al., 2020; Saba et al., 2023).

According to 2017 data, cereals and milk were the two most significant dietary protein sources for human consumption, with fish and marine products ranking third (FAO, 2021). However, aquaculture has recently faced numerous challenges, including increased viral diseases exacerbated by warming temperatures (Reverter et al., 2020) and the overuse of antibiotics (Dawood et al., 2020). Addressing these challenges necessitates sustainable feed methods. In 2018, fed aquaculture accounted for about 69.5% of global aquaculture production, highlighting the significant demand for aquafeeds (FAO, 2020). According to IFFO (2020), the supply gap for aquafeed ingredients is projected to be around 30 million tons by 2030.

Fishmeal and fish oil, primarily sourced from wild-caught fish and a small portion from processed fish, remain the main ingredients in aquafeed (Mitra, 2021). However, price fluctuations due to supply and demand imbalances have reduced the inclusion of fishmeal in aquafeeds, increasing reliance on wild fish stocks (Mitra, 2021). Fish farmers are working tirelessly to reduce feed costs, constituting more than half the total expense of raising fish. Extensive research is underway to develop more cost-effective feed alternatives to boost fish and shrimp production.

Plant-based ingredients such as sesame meal, soybean meal, rapeseed meal, cottonseed meal, cassava starch, and maize gluten meal can be used as substitutes for fishmeal in fish diets without compromising nutritional value (Prabu et al., 2017). Sustainable approaches that promote fish growth and health are essential to meet the growing demand for fish as a protein source. Hence, discovering effective and safe methods to enhance the well-being and development of fish in the aquaculture sector is crucial (Sokoti et al., 2021).

Several more sustainable feed ingredients, including plant-based oils and proteins, yeast, insects, and algae, serve as alternatives. Olive plants have gained popularity due to their numerous health benefits, with the Mediterranean region emerging as the leading producer over the past 20 years (Manzanares et al., 2020). This paper investigates the potential benefits of olive plants in aquaculture by examining their effects on fish growth and immune responses.

Role of blue foods in aquaculture and their nutritional importance

In developing countries, blue foods are among the most traded food products, with their net revenue from trade exceeding that of all other agricultural commodities combined (Tigchelaar et al., 2022). Blue foods are vital to nutrition and food security for billions of people. They are also central to many coastal and riverine communities' livelihoods, economies, and cultures while providing essential nutrition to the growing global population (Golden et al., 2021).

Blue foods are helping to achieve the United Nations Sustainable Development Goal (SDG) 2 of "zero hunger" by reducing dependence on limited natural resources. However, more innovation and new approaches are needed to make the sector more sustainable and "circular," mainly when sourcing the essential ingredients for aquafeeds (Colombo et al., 2023). Blue foods are highly diverse, rich in essential micronutrients and fatty acids, and can be produced through environmentally sustainable methods compared to terrestrial animal farming.

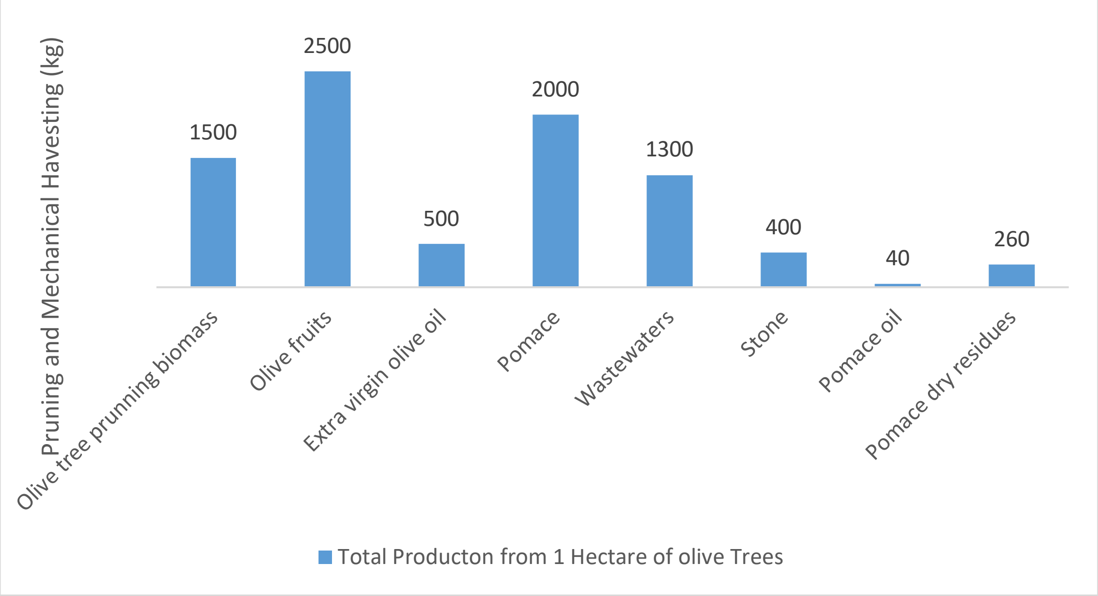
Human diets include approximately 2,500 aquatic organisms, ranging from freshwater and marine animals to plants and algae (Golden et al., 2021). According to Short et al. (2021), blue food systems are supported by various habitats integrated into agricultural systems, giving communities access to nutritious food through local and international markets. These systems are foundational to nutritious diets, supporting overall well-being.

The bioavailable micronutrients in blue foods help protect against stunting cognitive impairments and reduce the risk of maternal and infant mortality. Blue foods are also rich in healthy fats, which can help reduce obesity and non-communicable diseases, making them a healthier source of animal protein than livestock raised on land (Golden et al., 2021). In addition, the necessary lipids found in blue foods play a crucial role in lowering the risks of obesity and other non-communicable diseases (Golden et al., 2021).

Production Process of Olive Trees

Olive tree cultivation is a complex agricultural process that produces various products and by-products. These include olive tree pruning biomass, olive fruits, olive oil, pomace, wastewater, olive stones, pomace oil, and dry pomace residues. Each of these components has its production metrics and significance (Figure 1). The variety of products and by-products generated from just one hectare of olive trees underscores the multifaceted nature of olive cultivation.

Figure 1.
Production from 1 Hectare of Olive Trees (Espeso et al., 2021)



Olive trees require regular pruning to remain healthy and productive. Each hectare of olive trees produces approximately 1,500 kg (1.5 to 5 tons) of pruning biomass annually. This biomass has various applications, including being used as mulch, compost, and a renewable energy source. The primary product of olive farming is the olive fruit. Well-maintained olive trees can yield around 2,500 kg (3 to 7 tons) of olives per hectare yearly (Rodríguez et al., 2019; Ahmad et al., 2024).

The harvested olives are processed to extract olive oil. Depending on the extraction method and oil concentration, 100 kg of olives can produce 20 to 25 litres of olive oil. From 5 tons of olives, an estimated 1,000 to 1,250 litres of olive oil can be obtained. The solid residue left after oil extraction is known as pomace, which consists of water content, olive stones, pulp, and skin (Ying et al., 2017).

From 5 tons of olives, roughly 3 tons of pomace are generated. Pomace can be used as compost, animal feed, or for biofuel production. It can also be further processed to extract pomace oil (Alonso-Fariñas et al., 2020). Refined pomace oil, which is of lower quality than virgin olive oil, is used for industrial purposes or human consumption. The dry residue left after extracting pomace oil can be used as fuel, fertilizer, or animal feed.

A significant amount of olive mill wastewater (OMWW) is produced during olive oil extraction. Around 6 to 7.5 cubic meters of wastewater are generated from processing 5 tons of olives. This wastewater contains organic compounds and must be treated before disposal (Alkhalidi et al., 2023). Olive stones, also known as pits, are a component of pomace but are often separated for specific uses. Four tons of olives yield approximately 400 kg of olive stones used for biofuel production, abrasives, and even activated carbon (Mallamaci et al., 2021; García Martín et al., 2020).

The Potential of Utilizing Natural Compounds from Olive Plants in Fish Farming

The production of high-quality fish feed is crucial in promoting notable growth, feed efficiency, and fish meat quality in aquaculture. Researchers are exploring alternative fish feed options, such as using olive plants, to complement or improve conventional aquaculture diets. Olive plants contain bioactive compounds that can enhance aquaculture by improving stress resistance, growth, appetite stimulation, tonicity, immune response, and even reproductive health in fish. These bioactive compounds include phenolics, glycosides, alkaloids, terpenoids, saponins, tannins, flavonoids, steroids, and essential oils (Hodar et al., 2021; Farag et al., 2020).

Over the past decade, medicinal plants have become a popular alternative in aquaculture due to their abundance of bioactive compounds (Zhu, 2020). Administering plant extracts to farmed fish has been shown to increase feed intake and promote weight gain (Gupta et al., 2021). Additionally, plant extracts improve nutrient availability and digestibility, leading to enhanced feed conversion rates and higher protein synthesis (Chojnacka et al., 2021). Diets enriched with plant-based compounds boost fish immune function, digestive enzyme activity, antioxidant capacity, and overall growth (Zemheri-Navruz et al., 2020).

In recent years, there has been increased interest in using functional feed supplements to enhance fish's immune systems and improve their overall health, thus increasing disease resistance. Reverter et al. (2020) reported that plant-based alternatives are cost-effective and practical in various aquaculture systems, with efficacy against various pollutants. Various studies have examined the effects of intraperitoneal injections or oral administration of plant extracts on different fish species. The results indicate that fish treated with plant extracts show elevated respiratory burst activity, increased plasma protein, enhanced lysozyme activity, improved phagocytic function, and more vigorous complement activity (Elumalai et al., 2021; Yakubu et al., 2020).

These findings suggest that incorporating olive plants or olive oil into fish diets can improve fish health and strengthen their immune systems, reducing the incidence of disease in aquaculture. According to Dawood et al. (2018), immune stimulants can be viable alternatives to vaccines and antibiotics in disease prevention and management. Due to their numerous advantages—including minimal environmental impact, no risk of drug resistance, affordability, and accessibility—plant-based immune stimulants are the preferred choice among available immune stimulants (Gabriel, 2019).

The olive tree (*Olea europaea L.*) is one such plant used in herbal remedies. Its leaves and fruits are the most valuable parts of the plant (Gokdogan & Erdogan, 2018). Olive leaves contain natural bioactive compounds, and numerous studies have demonstrated the positive effects of olive leaf extracts on aquatic species, such as improved immunity and survival rates. Olive plants are also known for their antiparasitic properties against fish infections (Alagawany et al., 2020). Baba et al. (2018) reported that administering 0.1% olive leaf extract increased the survival rates and serum biochemical markers of *Oncorhynchus mykiss* (rainbow trout). Similarly, Zemheri-Navruz et al. (2019) provided *Cyprinus carpio* (common carp) with four doses of olive leaf extract. Their results showed that a diet containing 1 g/kg of olive leaf extract improved fish immune parameters and survival rates.

In addition, studies have assessed the effects of olive leaf extract on *Cyprinus carpio* growth performance, haematological parameters, immune response, and carcass composition (Sokooti et al., 2020). These findings suggest that vegetable oils, such as olive oil, in aquaculture may replace fish oil. Therefore, olive oil can be a valuable feed source in aquaculture.

2. Background

Historical Applications and Significance of Olive Plants

The olive tree (*Olea europaea* L.) belongs to the Oleaceae family and has played a significant role in the agricultural practices of many Mediterranean populations. For over 6,000 years, the Mediterranean basin has been a hub for the cultivation of olives, which are now grown commercially. New olive plantations have also been established in regions like California, South Africa, Australia, Chile, and Argentina. Numerous distinct cultivars have emerged from non-scientific selection methods.

The olive tree thrives in hot, dry climates, requires minimal water during flowering, and can withstand adverse conditions with just occasional cold periods. Evidence suggests that humans and olives have coexisted for 5,000 to 6,000 years (3150–1200 BCE). The spread of the olive tree likely coincided with the trade of other important crops like date palm, grapevines, and figs. Historical texts, including Hebrew, Bible, and Quranic scriptures, reference olive plants and fruits, offering valuable insights into the cultural and environmental relationships of Middle Eastern societies.

One of the most significant uses of the olive plant across various cultures was as a source of fuel for lamps. Olive oil also played an essential role in rites and ceremonies, including the anointing of warriors, rulers, and ordinary people. Today, the majority of the world’s olive oil is produced in Europe, making olive oil production a cornerstone of the Mediterranean agricultural economy. Though olive oil has been a staple of Mediterranean cooking for centuries, its global popularity has surged due to its health benefits (Alemán et al., 2016).

Historically, olive oil has been used in therapeutic ointments to treat various ailments, as well as in religious sacrifices and rituals. Additionally, olive oil was used to enhance physical appearance, particularly for hair and skin care.

Exploration of Bioactive Compounds Found in Olive Plants and Their Potential Benefits for Fish Health and Growth

In the agricultural industry, olive cultivation and olive oil production generate several by-products, such as olive leaves, olive pomace oil, and olive mill wastewater. The first documented use of olive and its derivatives in fish feed dates back to 2004 (Yilmaz et al., 2004). Since then, numerous studies have shown the positive health effects on fish, including enhanced immunity and improved carcass composition, depending on the derivative used and the fish species studied.

Olive trees are biochemically rich in secoiridoids, carbohydrates, sugar alcohols, flavonoids, and terpenoids (Centrone et al., 2021). According to Guinda et al. (2015), olive leaves contain important phytonutrients such as oleuropein, oleanolic acid, oleocanthal, hydroxytyrosol, and mannitol (3% dry weight). These bioactive compounds are also found in other notable plants like *Pistacia vera* (pistachio), *Melissa officinalis* (lemon balm), and *Origanum vulgare* (oregano), offering broad potential for agricultural applications.

Studies have shown that these plant derivatives can enhance antioxidant capacity and immune-related genes in Nile tilapia (Mohammadi et al., 2022). Olive oil, which contains the highest percentage of monounsaturated fat among all edible oils (more than 70%), is rich in fat-soluble vitamins (E, A, D, and K) and anti-inflammatory substances.

The positive effects of olive oil derivatives on carcass composition have been documented in several aquatic species, including rainbow trout, gilthead sea bream, African catfish, and red sea bream (Arsyad et al., 2018). Of all the olive oil derivatives, pomace has been shown to significantly influence fatty acid content in fish. Refined olive pomace oil contains bioactive components such as oleic, linoleic, stearic, palmitic, and palmitoleic acids, which can regulate immune function and help prevent infections (Hazreen-Nita et al., 2022).

Abdel-Razek et al. (2017) noted differences in the phenolic components of olive leaves, olive oil, and olive pomace. Olive pomace has been successfully utilized in livestock and aquaculture as a feed ingredient due to its high protein content and cost-effectiveness, offering a valuable alternative to conventional protein sources. Studies have demonstrated that olive pomace can replace wheat meal in tilapia diets without negatively affecting growth performance or feed efficiency (Yildirim and Guroy, 2015).

The use of olive pomace meal as a feed ingredient has been shown to develop more affordable feedstuffs for aquaculture. Since olive pomace is a natural by-product that is inexpensive and non-genetically modified, it has become a sustainable alternative in fish diets. Moreover, the inclusion of olive pomace in tilapia diets does not negatively affect feed acceptance or taste (Yildirim and Guroy, 2015).

Olive oil derivatives have also been used as partial replacements for fish oil in aquafeed due to their benefits for intestinal health and microbial diversity. Feeding fish with olive oil extracts has been shown to increase goblet cell populations in the intestinal epithelium (Gisbert et al., 2017). Additionally, extra virgin olive oil and its derivatives, such as hydroxytyrosol, tyrosol, and oleuropein, have demonstrated anti-allergic properties in fish, primarily detected in the intestinal lumen (Centrone et al., 2021).

Furthermore, research has shown that vegetable oils, such as olive and rapeseed oils, substituted for fish oil in fish feed, result in lower cholesterol levels in fish intestinal tissue compared to fish oil (Liland et al., 2018). Olive oil derivatives also stimulate the growth of *Lactobacillus acidophilus*, a probiotic that benefits gut microbiota in fish (Banerjee and Ray, 2016; Gavahian et al., 2019). Bioactive compounds from olive oil by-products have been shown to improve the intestinal mucosal immunity of gilthead seabream (Gisbert et al., 2017).

3. Methodology

A thorough search of all peer-reviewed journal articles and theses from Google Scholar was used to examine the significance of aquaculture in providing sustainable food sources and the impact of olive plant compounds as a blue food on the growth, immunity, and disease resistance of fishes from 2015 to the present. A literature search was performed, and the following keyword combination was used: (Sustainable) AND (aquatic) AND (blue food) AND (olive plant). Articles were reviewed to determine whether they met the following criteria of the paper: i) Explore how olive plant crop extracts can promote the growth of blue food species. ii) Evaluate how aquatic creatures' health and disease resistance are affected by the immunological impacts of crop products from olive plants. iii) Optimise olive plant crop extracts' composition and application techniques for optimal effectiveness in aquaculture systems. iv)Investigate possible mechanisms behind the increase of immune function and encouragement of growth in aquatic organisms caused by crop derivatives from olive plants. v) Establish the ideal proportions of olive plant derivatives in blue food formulations to boost immunological response and growth. Find patterns, trends, and gaps in the literature to synthesise and summarise the extracted data. Sort the results according to significant themes, such as how aquatic species' ability to thrive, fight disease, and act as an immune system is affected by derivatives of olive plants. Consider differences in methodological techniques, species-specific responses, and experimental settings between studies. Other considerations imply analysing the economic and environmental advantages of aquaculture techniques using crop derivatives from olive plants. Suggest the environmentally responsible incorporation of crop derivatives from olive plants into aquaculture enterprises. To help aquaculture stakeholders transfer and accept new information, disseminate research findings through this publication in academic journals and outreach initiatives. Cooperation and collaboration between researchers, producers, and industry stakeholders should be encouraged to encourage the adoption of cutting-edge techniques for sustainable aquaculture development. Provide evidence-based tactics to enhance growth, health, and sustainability in blue food production systems, thereby advancing aquaculture methods.

4. Importance of Nutritional Components in Aquatic Organisms

Nutrition is an important factor that needs to be addressed for aquaculture to be affordable and sustainable. Nutritional components in aquaculture are the science of a nutrient's interaction with some element of a living organism, such as feed composition, ingesting, energy release, waste disposal, and synthesis for maintenance, growth, and reproduction (Prabu, et al., 2017). Feeding the fish with nutritionally enriched feeds may dramatically increase the overall production. Therefore, nutrition is one of the essential areas that the aquaculture industry should focus on. Aquaculture nutrition contribution varies greatly, not only on the species raised and fed (Fry et al., 2016; Tacon et al., 2020) but also importantly on the operating environment social and economic context of production and distribution systems. Due to their high nutrient quality, aquatic animals are effective and necessary food sources for enhancing the nutritional state of the nation's population (Fujita et al., 2019).

Fish's development, ability to reproduce, overall health, and reaction to infections, physiological and environmental stressors are all influenced by their diet and feeding habits. In aquaculture, nutrition is the most important feature. Providing the fish with enriched feed high in nutrients can significantly boost their overall yield. Thus, nutrition is one of the most important areas on which the aquaculture business should concentrate. It is necessary to assess the nutritional contributions of seafood, which calls for a systems approach to comprehend its distribution and the financial value it adds to the product trends (Gephart et al., 2021; Gleadall, et al., 2024). It has been reported that olive is a good source of phenolic compounds with antioxidant activity (Fernández-Prior et al., 2020).

Aquatic animals absorb nutrients from the water by feeding on plants, seeds, fruits, and tubers, then recycle those nutrients as they decompose. Aquatic organisms require carbohydrates, protein, minerals, vitamins, lipids and other feed additives to meet the physiological needs of growth and reproduction (Prabu, et al., 2017).

Protein in the aquatic diet provides ten important amino acids, while fat provides vital fatty acids. The diet also contains fat-soluble and water-soluble vitamins. Combination of the aquatic feeds with water supply minerals. Protein Protein is the most important consideration when developing blue feed formulations. It is the most expensive and essential factor influencing aquatic species' development and nutritional performance (Henchion et al., 2017). Protein provides energy and amino acids and meets functional proteins' dietary requirements. Amino acids are necessary in protein for the fish diet, but not all amino acids are digestible. According to research, amino acid needs of different fish species vary significantly (Mohanty et al.,2019). Most characterized olive proteins are located in the fruit, mainly in the seed, where different oleosins and storage proteins have been found. There are other parts of olives that contain lower amounts of protein, such as olive pulp, which could also serve as a nutrient enrichment for blue food production.

Carbohydrates for fish diets, the most cost-effective and affordable energy source is carbohydrates. They are not necessary in fish diets but are utilized to reduce feed costs. Carbohydrate content should not be higher than the protein in the feeds. Fish can efficiently break down simple carbohydrates but difficult to digest complex ones (Sadasivam et al., 2022). Their digestion ability varies with species; Warm-water fish can more easily digest food carbohydrates than cold-water fish. Different animals use carbohydrates differently as an energy source. Glycogen buildup and hepatic enlargement might result from eating too many carbohydrates. Craig et al., (2017) reported that a few amino and nucleic acids can be synthesized from carbohydrates, promoting growth.

Fat, the amount of fat in the food, the kind of fat, the temperature of the water, the degree of unsaturation, and the length of the carbon chain all affect how digestible fat is. Dietary fats supply essential fatty acids (EFA), which are necessary for appropriate growth and development in fish and are a significant source of energy for fish (Mejri, et al., 2021). Fish can derive their nutrient from olives. Olives contain 11–15% fat, 74% of which is oleic acid, a monounsaturated fatty acid. It is the main component of olive oil. Vitamins Organic substances called vitamins are needed in the diet for proper development, reproduction, and health. They participate in a range of bodily chemical processes.

Fish diets require vitamin supplements because of their straightforward digestive systems (Caipang and Lazado, 2015). There are two types of vitamins: fat-soluble and water-soluble. Choline, Thiamin, Myoinositol, Riboflavin, Vitamin C, Folate, Niacin, Biotin, Pyridoxine, and Vitamin B12 are among the water-soluble vitamins. Myoinositol, choline, and vitamin C have several uses. Choline serves as a methyl group supplier for chemical reactions, a component of membranes, and a precursor to acetylcholine, a neurotransmitter. Myoinositol is a signaling agent that is used in several physiological functions. Vitamin C plays a role in bone marrow production, wound healing, and connective tissue formation. It also prevents tissue lipids from peroxiding and makes iron easier to absorb from the colon. Most of the water-soluble vitamins function as coenzymes in the body's metabolic processes. Fat-soluble vitamins are vitamin A, vitamin D, vitamin E, and vitamin K. Together with dietary lipids, fat-soluble vitamins are absorbed in the intestine. Fat-soluble vitamins, as compared with water-soluble vitamins, can be retained in bodily tissues. Phosphate Dietary phosphate is the source of phosphorus; it prevents bone deformities, increases feed efficiency, and prevents poor growth. Phosphorus is a necessary nutrient for the formation of blue foods. it is essential for several physiological functions in fish, including bone formation, tissue growth, acid-base balance maintenance, energy metabolism, and reproduction. Numerous factors, such as species, life stage, growth rate, and water temperature, affect fish phosphorus requirements (Suguira, 2015).

Growth and skeletal development are linked to higher phosphorus requirements, which is especially intriguing for fish raised for food. One of the three key nutrients is phosphorus, which olive roots mostly take as orthophosphate. In activities involving Adenosine diphosphate (ADP) and Adenosine triphosphate (ATP), phosphate plays an essential role in transmitting and storing energy for use in later growth and reproduction processes. Calcium The chemistry of water dictates how much calcium is needed. Fish absorb calcium directly from water by its gills and skin (Sanderson et al., 2021). The combination of calcium and phosphorus in fish bodies makes maintaining the blue food diet crucial.

Microminerals Fish's health depends on microminerals, even though they are only found in trace amounts in their bodies. Copper (Cu), Iodine (I), Iron (Fe), Manganese (Mn), Selenium (Se), and Zinc (Zn) are among the microminerals. Copper (Cu) Cu is an essential microelement required for aquatic organisms to grow and thrive to their full potential; it supports several physiological, metabolic, and biological processes across the aquatic animals' whole bodies (Dawood, 2022). Many enzymes include Cu, which is necessary for their function. Although Cu is necessary for fish health, it can be hazardous at concentrations of 0.8 to 1.0 m per litre of water. Cu is more easily absorbed by fish from feed than water (Saha et al., 2024). Iodine (I) The thyroid gland needs iodine to produce hormones. Iodine can be found in both water and fish food. Iron is required to develop heme compounds (haemoglobin and myoglobin) (Ems et al., 2024). Iron (Fe) Sufficient dietary iron supplementation enhances antioxidant status, feed utilization, and development. Fe plays a major role in oxygen transfer, electron transport, and cellular respiration, emphasising the function of haemoglobin in fish.

Aquaponics rely on bacteria to convert nutrients, and these microbes' growth requires Fe (Farooq et al., 2023). Iron can be used as a component for aquafeeds and may aid in improving palatability and increasing feed intake (Glencross, 2020). High Fe intake may cause fish to grow more slowly, probably because it is poisonous (Evliyaolu et al., 2022); dietary Fe will enhance the quality of fish feed used in aquaculture. Manganese (Mn) Manganese serves as a cofactor or component of enzymes. Manganese metabolism, lipid buildup, growth, and antioxidant capability were all enhanced at an ideal dietary level. For living things to continue having regular metabolic and physiological processes, manganese (Mn) is a necessary micronutrient. Growth and feed utilization were improved with an ideal dietary manganese (Mn) level. Manganese is an essential trace mineral for skeletal growth and development. Inadequate mineralization, a rise in skeletal anomalies, and stunted growth can result from dietary Mn deficiencies (Lall and Kaushik, 2021). Selenium (Se) Selenium offers defense. Cells and membranes are shielded from the peroxide threat by selenium. Several fish species have been found to have better overall growth when their diets contain adequate selenium levels. Sufficient selenium addition in feed has been linked to increased growth rates, weight gain, and feed efficiency in producing blue foods. It is only a very potent antioxidant and is crucial to fish's antioxidant defence system. Aquatic species' intestines and liver are healthier when they consume dietary nanoselenium. The pigment and phenol content of extra virgin olive oil enhanced with selenium significantly increased (D’Amato et al., 2017). Zinc (Zn) Zinc is also found in many other enzymes. Zinc consumed through feeding works better than zinc dissolved in water for blue food production. The types of phytic acid protein, dietary calcium, phosphorus, and zinc all affect how well zinc is absorbed and used in the blue food system (Prabu et al., 2017).

Growth retardation, cataracts, fin and skin erosion, dwarfism, and even mortality can result from a zinc deficiency. Ten of these olives would provide over 80% of the recommended zinc intake. (Hazreen-Nita, et al., 2022) Other trace minerals There is little evidence to support the potential importance of other trace minerals, including chromium and fluoride. Other elements that can impact fish health are present in many fish diets. While some of these components are added, others are natural. These elements include water, fibre, hormones, antibiotics, antioxidants, colours, binders, and feeding stimulants. In several animals, protection against muscular dystrophy requires vitamin E and selenium.

Current Research on Olive Plant Extracts in Aquaculture

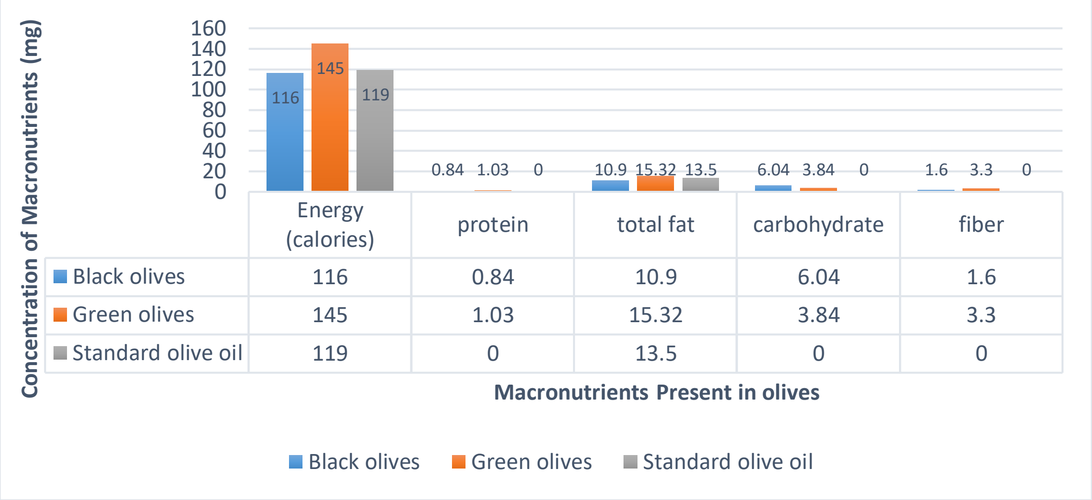
Blue food supplements and stimulants are added to aquatic diets to improve growth, immunity, growth, survival, efficient feed use, and digestion. Olive plant extracts were discovered to be an effective additive against viral infection in fish and other blue foods such as crustaceans. Because of their high protein content, many olive byproducts are also considered beneficial as feed additives. *Olive pomace* is a known olive plant byproduct, widely utilized in the livestock and aquaculture sectors. It has been extensively used in several ways, especially in animal nutrition. Given the increasing focus on agro-industrial waste value addition and cost reduction, olive extracts can be a useful substitute protein source for feed formulation. Rahman et al. (2021) report that feeding livestock and aquaculture species with agriculture industry byproducts is a frequent practice worldwide. Utilizing agricultural byproducts reduces the expenses related to animal feeding and waste management, as well as their dependency on grains (Mat et al., 2021). According to Fazio et al. (2021), fishmeal supplemented with 1% olive extracts can boost Oreochromis niloticus and Nile tilapia immune systems while accelerating their growth. Sokooti et al. (2021) and Arsyad et al. (2018) reported similar findings in research, which suggested that fish texture and quality might be enhanced by supplementing feed with olive leaves. According to a study by Arsyad et al. (2018), olive leaves can improve the quality of fish texture since they contain a much higher amount of collagen and myofibril than fish in the control group. Therefore, giving fish feed enriched with 0.1% or less of olive extracts for 40 days or longer can greatly strengthen their immune systems and increase their resistance to various diseases.

Olive extract was added to the shrimp meal for seven days before the study sample Penaeus vannamei (white leg shrimp) was exposed to the white spot syndrome virus (WSSV). A meal enriched with 0.02% olive extracts was given to experimental shrimp, and these shrimps had the greatest observed survival rate (65%). Olive extract was found to strengthen the crustaceans' immune system. Furthermore, studies have shown that fish treated with olive extracts can survive in environments with low water quality. Rajabiesterabadi et al. (2020) corroborated the claim that fish health is enhanced, and olive extracts mitigate the harmful effects of ammonia toxicity. According to Rajabiesterabadi et al. (2020), common carp fish were tolerant of high concentrations of ammonia at 0.5 ppm when fed feed supplemented with 0.1% olive extract for 60 consecutive days. Olive leaf extract was tested on Common carp (*Cyprinus carpio*) for 75 days; it shows that weight gain, specific growth rate and protein efficiency ratio values were significantly higher in the groups fed the diet containing 200 mg/kg of olive leaf extract compared with the control group (Sokooti et al., (2021). Olive leaf extract was tested on Nile tilapia (*Oreochromis niloticus*), with 1% extract in 2 months, and the immunity, growth and health of fish was enhanced (Fazio et al., 2021). Persian sturgeon (*Acipenser persicus*) is shown to have a lower FCR and higher specific growth rate after two months of feeding with 5% olive oil (Hosseinnia et al., 2021). Olive oil was used as a partial or total dietary replacement in feeding young yellowtail (*Seriola quingqueradiata*) for 40 days; it prevents discolouration of dark muscle without affecting the growth of young yellowtail (Seno-o et al., (2008). Improved growth rate and feed utilization were witnessed after feeding Rainbow trout (Oncorhynchus mykiss) with 2.5 g Olive waste kg−1 for six weeks (Hoseinifar et al., 2020).

Nutritional Content of Different Types of Olive that can Serve as an Additive to Blue Food Production

The nutritional content of different olives (black and green) shows that they are richly embedded with macro-nutrients, minerals, vitamins, and other trace elements that can improve blue food production. Macronutrients are essential for the growth and health of aquatic organisms, playing a critical role in boosting the production of blue foods such as blue-green algae, fish, and shellfish (Elegbede, et al, 2023). The macronutrient content of green olives, black olives, and standard olive oil varies due to their preparation and composition differences. These values provide an average nutritional composition and can vary slightly depending on the olives and olive oil's specific type and processing method.

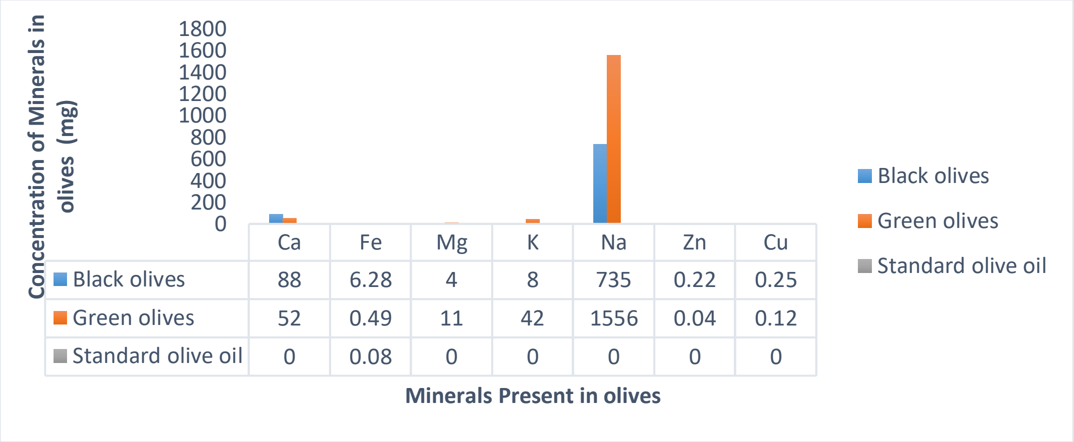
Figure 2.
Comparison of the macronutrient content per 100 grams for green olives, black olives, and standard olive oil (Rocha et al, 2020).



	Energy (calories)	protein	total fat	carbohydrate	fiber
🟦 Black olives	116	0.84	10.9	6.04	1.6
🟧 Green olives	145	1.03	15.32	3.84	3.3
⬜ Standard olive oil	119	0	13.5	0	0

Green olives are usually harvested before ripening and often cured in a brine solution. Black olives are typically harvested when fully ripe and cured in brine or other solutions. Standard olive oil is typically extracted from ripe olives through pressing or other extraction methods. Figure 2 It is almost entirely composed of fat.

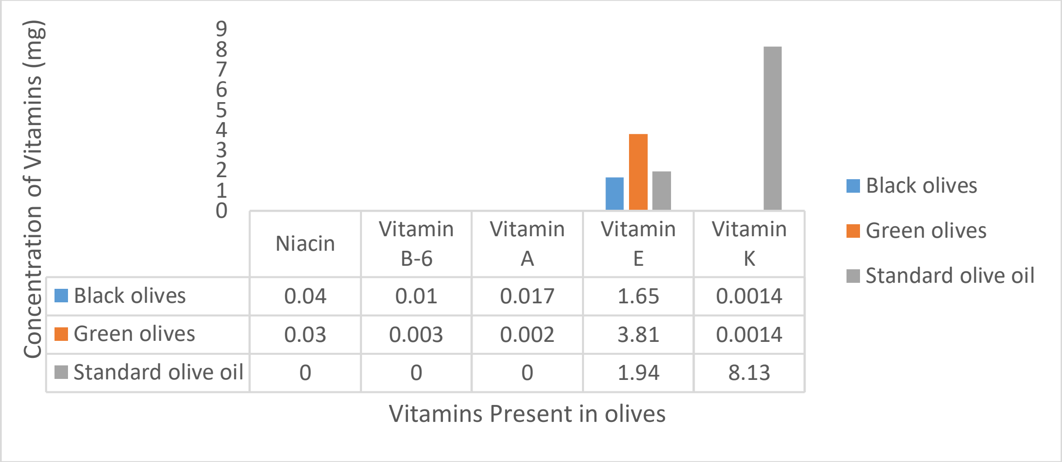
Figure 3.
Minerals present in 100 grams (g). of different olives (USDA 2020 a,b).



	Ca	Fe	Mg	K	Na	Zn	Cu
🟦 Black olives	88	6.28	4	8	735	0.22	0.25
🟧 Green olives	52	0.49	11	42	1556	0.04	0.12
⬜ Standard olive oil	0	0.08	0	0	0	0	0

Green olives, black olives, and standard olive oil are all derived from the same fruit but differ significantly in their processing and, consequently, their nutritional profiles. Green olives are high in sodium and moderate in calcium, iron, magnesium, potassium, and phosphorus (Figure 3). Black olives are high in sodium and calcium, significantly higher in iron, but lower in magnesium, potassium, and phosphorus than green olives. Standard olive oil is shallow in minerals compared to green and black olives, with only trace amounts of iron; there are no values for others. These differences highlight the impact of processing on the nutritional content of olives and their derivatives. While olives are good sources of several essential minerals, olive oil, valued more for its healthy fats and antioxidants, does not provide significant mineral content. These mineral contents can be highly valued for blue food production.

Figure 4.
Vitamins Present in different 100 grams (g) olives (Lanza and Ninfali, 2020; Delgado et al., 2017)



	Niacin	Vitamin B-6	Vitamin A	Vitamin E	Vitamin K
Black olives	0.04	0.01	0.017	1.65	0.0014
Green olives	0.03	0.003	0.002	3.81	0.0014
Standard olive oil	0	0	0	1.94	8.13

Green olives are rich in vitamins A and E and contain moderate vitamins K and B3 (niacin). Black olives can provide slightly less vitamin A than green olives but have comparable levels of vitamins E and K and slightly higher amounts of vitamin B3 (niacin). Standard olive oil is high in vitamins E and K, with minimal amounts of vitamin A (the value is not indicated) and almost no water-soluble vitamins (such as B vitamins and folate) (Figure 4). These differences are primarily due to the stage of ripeness at which the olives are harvested and the processing methods used to produce olive oil. While whole olives are a good source of various vitamins, olive oil is particularly rich in vitamins E and K, making it beneficial for heart health and as an antioxidant. Vitamin E and vitamin K play vital roles in the health and productivity of aquatic ecosystems, including aquaculture and the cultivation of blue foods like blue-green algae, certain fish, and shellfish (Kumar, 2017).

Effects of Olive Plant Compounds on Fish Growth

Natural feed additives contain active compounds that influence aquatic animals' growth performance. Plant proteins are the most practical option because they are widely available and reasonably priced. Consequently, ongoing interest has been in expanding the global aquaculture business to identify and develop plant-based components to replace fishmeal and its high cost (Kari *et al.,* 2022). When formulating fish feed, it is crucial to ascertain the ideal amount of plant protein source inclusion. High inclusion rates adversely affect fish growth and health outcomes (Hosseinnia *et al.,* 2021; Zulhisyam *et al.,* 2020). Several research on growth performance has been carried out to determine the effects of plant products on aquaculture (Zemheri-Navruz *et al.,* 2019).

Varied fish species showed improved weight gain, feed efficiency ratio, nutrient digestibility, and excellent disease resistance when varying concentrations of herbal extracts were applied (Xu *et al.,* 2020). Nutritional enrichment with 1% olive is recommended for carp feed formulation since it promotes specific immunological and antioxidant characteristics in common carp. It also remarkably affects growth performance, digestive enzyme activity, and growth hormone in four tissues (brain, muscle, liver, and head kidney.

Nonetheless, avoiding higher concentrations of raw olives is suggested since they may result in hepatotoxicity and oxidative stress (Hoseini *et al.,* 2021). Aquaculture aims to increase products of higher quality and quantity so aquatic organisms can grow more quickly when given the correct number of extracts from olive leaves in their typical diets. Therefore, using olive as a feed additive in fish production appears feasible and environmentally benign.

Immunological Effects of Olive Plant Compounds on Fish

Fish immune system reactions are controlled by various cells that release soluble mediators that work systematically to provide complete protection. The innate (non-specific) and adaptive (specific) immune systems are the two components of the immune system in fish and other higher vertebrates. The fish immune system consists of lymphocytes (T cells, B cells) and phagocytes (monocytes and neutrophils); leucocytes are considered the backbone of all immune responses. Lymphoid organs categorized into tissues and organs used in the immune responses. Fish have three primary lymphoid organs: the thymus, head, kidney, and spleen, and secondary lymphoid organs, which include the gut, liver, and gills (Mustafa and AL-Taee, 2020). There has been much interest in using medicinal plants in aquaculture since they supply safe and environmentally beneficial ingredients. These substances operate as chemical and conventional antibiotic substitutes, boost immunological responses, and manage fish illnesses (Ghosh *et al.,* 2021). As an inexpensive source of protein, many medicinal plants have been employed successfully to replace the protein in fishmeal. Medicinal plants can simultaneously function as an immunomodulator and a growth stimulator. Because they are rich in a wide range of nutrients and chemical compounds, medicinal plants are employed in the aquaculture industry as feed additives and chemotherapeutics (Dawood *et al.,* 2018). Medicinal plants such as olive have shown a wide range of biological effects, which include promoting growth, enhancing appetite, boosting immunity, acting as an antibiotic, and reducing stress in fish.

Furthermore, the existence of numerous active components, including phenolics, alkaloids, tannins, saponins, glycosides, and flavonoids, is thought to be responsible for the mode of action of those plants and their derivatives (Alamgir, and Alamgir, 2018). Large-scale uses of plants in aquaculture to simultaneously provide better growth and protection are also encouraged by their low price and ease of access. They have been used in various ways, either as crude, plant extracts, or active ingredients. They are occasionally combined with a livestock product or a probiotic (Holkem, *et al.,* 2023). According to recent research and inferences, olive leaf extract offers enormous potential for use as an immunostimulant agent in aquaculture. These results demonstrated that an extract from olive byproducts has immunostimulant qualities that can strengthen fish raised for commercial purposes' resistance to a range of infections and diseases (Hazreen-Nita *et al.,* 2022).

Mechanisms Underlying Olive Plant Compounds for Fish Growth and Immunity

Due to the abundance of bioactive compounds found in medicinal plants, such as steroids, phenols saponin, polysaccharides, and flavonoids, these products have been proven to improve fish growth, immunological responses, appetite, antioxidation, and control reproduction. Improvements in humoral, mucosal immune parameters and antioxidant enzyme activities are typically correlated with fish growth rates performance (Hoseinifar *et al.,*2020). Baba et al. (2018) study on *Oncorhynchus mykiss* reveals that the species' serum biochemical parameters and survival rate were improved by olive oil leaf. Due to their beneficial biologically active metabolites, olives as a medicinal plant have indicative effects on growth promotion, appetite-stimulating and digestive enhancement. When appropriately administered for immune modulation, medicinal herbal extracts are a promising alternative to synthetic drugs in aquaculture.

Application and Sustainability in Aquaculture

Aquaculture feeds are designed with a balanced nutrient content to fulfil the needs of various species. They provide all the essential nutrients and energy required to meet the physiological demands of fish. Blue foods have advantages over other animal-based foods in many regions of the world, including accessibility, affordability, and health benefits (Ryckman *et al.,* 2021). Optimizing nutrition provided in aquaculture is therefore necessary to raise fish for food production. Atlantic salmon (*Salmo salar*) diets have been studied by substituting terrestrial plant oil from olive (Glencross *et al.,* 2014) for fish. Blue foods typically have lower environmental footprints than many other foods derived from animals (Gephart *et al.,* 2021). Sustainability in the aquaculture sector is of social, economic, and environmental importance. Producing an enormous diversity of blue foods, these systems encourage robust diets and adaptability to market swings and global warming. Blue foods can also play a significant role in socio-economic practices, cultural heritage, and wealth opportunities (Ban *et al.,* 2019). Aquafeed production requires sustainable alternative feed sources. The most practical substitute sources are terrestrial plant and animal-based materials, and recent findings on insects and byproducts from fisheries and aquaculture have also been found.

5. Conclusion

Blue foods are the cheapest protein and have higher benefits to human nutrition. Using plant-based materials in their feeds has shown to be a crucial way to lessen aquaculture's dependency on wild fish. Technological advancements presented a great opportunity to consistently produce high-quality olive oil and derivatives with improved nutritional profiles for blue food. Olive derivatives possess antioxidant, antibacterial, antimicrobial, antioxidant, antifungal, and antioxygenic properties, enhancing fish's intestinal health and immunological response. The nutritional value of all olive plant derivatives, such as olive cake, olive leaves and branches, or vegetative waters, should not be ignored. Research into the potential benefits of olive plants and derivatives for various fish species' diets has a positive impact and can be used continuously for utilization. Given the substantial benefits reported here, adding olive derivatives to feeds utilized by blue foods does not negatively affect growth performance. Going forward, olive crops and derivatives can be utilized in blue foods; however, an extraction and purification process for essential polyphenols must be developed. Adding these derivatives to blue foods solves the problem of managing agricultural waste. More developmental studies are needed to determine whether adding an olive plant or its derivatives to diets can enhance the nutritional value of blue foods.

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